

Testing the ion cyclotron resonance theory of electromagnetic field interaction with odd and even harmonic tuning for cations

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Abstract

Seeds of *Raphanus sativus*, var. *Cherry Belle* were exposed to combined parallel static and sinusoidal 60 Hz, 40 μ T peak–peak ac fields turned to the fundamental, 2nd and 3rd cyclotron resonance harmonics for calcium and potassium ions. Other seeds were exposed to similar fields tuned to the fundamental and 5th harmonic for magnesium. Concurrent controls consisted of seeds exposed to the ac field only, and to ambient geomagnetic and stray 60 Hz ac fields. After 21 d, plant height, aboveground weight, root weight, stem diameter, leaf length, leaf width and length/width aspect ratio were measured and compared to in-group controls. Calcium slowed germination, potassium speeded it, and magnesium left it unaffected. Calcium and magnesium tunings were generally stimulatory to growth, while potassium tuning was inhibitory, except for root weight. Controls (ac only) were unchanged from the ambient field controls. Fields at the 2nd harmonic were ineffective, except for potassium 2N, which appears similar to a weak calcium effect. The data support the ICR theory, but not the Paramagnetic Resonance theory of Lednev, or its expansion by Blackman and Blanchard as the Ion Paramagnetic Resonance theory.

Keywords: Cyclotron resonance; *Raphanus sativus*; Tuned fields; Resonance harmonics; Ca, Mg and K tunings; ICR theory

1. Introduction

Among the many theories which try to explain the effects of very low level ($< 100 \mu$ T) magnetic fields on biological systems is the Ion Cyclotron Resonance (ICR) model proposed by Liboff [1]. This model has been expanded to a considerable degree recently [2], and has been tested on a number of systems with successes and failures. One of the key features is that only the fundamental and odd harmonics for any ion should be effective. Even harmonics should have no effect. The original test system, marine diatoms [3], demonstrated a clear effect supporting the theory, but the organisms are fastidious, the experiments have been hard to duplicate, and the results appear to be strain-dependent. There are many reports in the literature of electromagnetic field effects on plants [4–6], including effects with 60 Hz ac fields. Hence, we decided to try a common plant species to see if the theory could be evaluated using a simple, inexpensive and universally available test system. The common garden radish *Raphanus sativus*, var. *Cherry Belle* was chosen for several reasons: the seeds are easily manipulated, being neither very small nor very large; the seedlings are similarly

easy to manipulate, for the same reasons; a large number of seedlings can be grown in a short time, and in very little space; the seeds are universally available and very inexpensive; and the experiments require no exotic equipment, other than a single-axis magnetometer. All of the other required elements can be purchased off-the-shelf for very modest sums, or easily constructed at low cost. As will be seen below, the system seems to work quite well, and the results so far seem relatively unambiguous, and follow expectations derived from previous efforts.

2. Materials and methods

2.1. Selection of seeds and preparation of test cultures

Fresh seeds (packed for the then current growing season) of *Cherry Belle* radishes were purchased from a local garden supply shop. They were stored at ambient temperature ($23.0 \pm 0.5^\circ\text{C}$) in their original packet on laboratory shelving.

Seed cups were prepared by first washing commercially available Perlite (Hyponex Corp., Marysville, OH) with

sterile distilled (12 M Ω) water (DW). The Perlite was washed and drained twice, with 10-min soaks between washes to remove any readily soluble organics or mineral elements. Pairs of plastic seed cups 5.5 cm long $\times$ 4.8 cm wide $\times$ 5.7 cm deep were loosely filled to the top with the moist Perlite, then the perlite was compressed to within 0.6 cm of the top. Five seeds were then selected to be placed in each cup by pouring seeds from the packet into a piece of paper folded into a “V”. This produced a line of seeds of random size. Successive seeds were placed in alternate cups at each numbered (1–4) corner, and in the center (5). Only broken or obviously misshapen seeds were discarded. The seeds were then covered with more Perlite to the rim of the planting cup. The planting cups were then inserted into 7 $\times$ 7 $\times$ 5 cm plastic trays (Rubbermaid) filled 3 cm deep with DW. Fluid levels were checked daily. On the 10th day of the experiment, the DW was replaced by a 1/10 v/v dilution of fertilizer solution containing final concentrations of 4.0 mg NH₃, 2.0 mg NO₄, 15.5 mg P₂O₄, 7.0 mg K, 25 μ g Mg, 1.50 mg S, 10 μ g B, 25 μ g Cu, 50 μ g Fe(II), 25 μ g Mn, and 25 μ g Zn per 100 ml (Plant Marvel Laboratories, Chicago, IL). From day 10 to 21 the fertilizer solution level was kept constant at the same level as the DW had been previously. The temperature averaged 23.0 $\pm$ 0.5°C, as measured with a digital thermometer (DAK Industries, Los Angeles, CA) calibrated against a NIST-referable standard. Light was provided by full-spectrum 40 W fluorescent tubes (GTE/Sylvania GL-40WT12) at 2800 $\pm$ 10 Lux on a 12/12 h (9:00am–9:00pm) daily schedule. The light level was measured with a Lutron LX101 Luxmeter (Edmund Scientific, Barrington, NJ).

Each experiment consisted of at least triplicate pairs of experimental and ambient control cups, so that n for each experiment was 15. If all seeds in any cup did not sprout, or when outlying data were discarded, another cup was prepared and run, and the resultant plants were measured until the total n was 15. In such cases, the extra seedlings were compared with controls or experimentals run concurrently, and the control or experimental plant corresponding to the number of the missing or discarded seedling was discarded from the original data set. In no case were more than 3 supplementary plants required to bring the data set to $n = 15$.

2.2. Field exposures

Experimental cups were exposed continuously to 60 Hz sinusoidal magnetic fields of 40 μ T p–p amplitude. The composite (geomagnetic vector + applied) static magnetic field parallel to the ac field was adjusted to various levels to conform to ICR tuning for calcium, magnesium and potassium ions, using the formula:

$$2\pi F_c = (q/m)B$$

where: F_c = Fundamental ICR frequency; q = charge on

the ion in coulombs; m = mass of the ion in kg; and B = static field strength in Tesla (T).

Harmonics were set by dividing the fundamental static field by the whole integer representing the harmonic. Thus, for calcium ions, the static field was set to 78.4, 39.2 or 26.1 μ T, the fundamental, 2nd, and 3rd harmonics. For potassium ions, the static fields were set at 153.3, 76.6 and 51.1 μ T, the fundamental, 2nd, and 3rd harmonics. An ac-only control was established by setting the static field to 0.0 μ T. For magnesium, the static fields were 47.5 and 9.5 μ T, representing the fundamental and 5th harmonic. The third harmonic for magnesium (15.8 μ T) was avoided, since it closely corresponds to the 5th harmonic for calcium (15.7 μ T). Results of such tuning will be reported later. Experiments at the 2nd harmonic for Mg are now in progress, and also will be reported separately. No experiments were set up using the static field values only, since in our laboratory, there was always some vector for the geomagnetic field which matched an effective selected static field value, and hence the ac-unexposed controls (Co) were in reality exposed to such static fields in some direction. The magnetic fields were generated between an 18 cm diameter pair of 400 turn No. 28 AWG (American Wire Gauge – ca. 0.8 mm diameter) enameled Cu magnet wire coils spaced 9 cm apart with their axes oriented to magnetic N–S. The ac field was produced by a Beckman FG2 (Emerson Electric Co., Brea, CA) function generator. The static field was set using the dc offset of the function generator. Field strengths were measured with a Schonstedt DM-2220 S5 single-axis fluxgate magnetometer (Schonstedt Instruments, Reston, Va). The dc field was read from the magnetometer digital display, while the ac field strength was obtained via the analog output connected to a PROTEK P-2015 15 MHz oscilloscope (Protek Instruments, Norwood, NJ). Frequency was monitored with a Beckman UC10 Universal Frequency Counter. Magnetic field parameters were checked daily, as were all other conditions. The magnetic fields (μ T, p–p) at the experimental site in the E–W axis were 0.0 static and 6.1 ac. In the Z (vertical) axis, the fields were 42.3 static and 4.0 ac. At the n -control (Co) location, the ambient fields were 21.5 static and 0.4 ac in the N–S axis; 0.0 static and 1.8 ac in the E–W axis; and 45.2 static and 4.0 ac in the Z axis.

2.3. Data collection and analysis

The time of emergence for each seedling was recorded. A seedling was recorded as having germinated when it was above the surface of the medium. The data were plotted as time vs. number emerged, and the slopes of the curves were compared statistically by regression analysis.

At the end of 21 d the seed cups were flooded gently with flowing room-temperature tap water, and the plants were removed from the cups by gently rocking them back and forth while applying traction. Adherent Perlite was gently rubbed from the roots, and the plants were patted

dry of all visible water. They were then allowed to stand for 5 min. At the end of the 5 min, the plants were divided with scissors at the stem/root junction; this point was easy to see since there was an abrupt color change. The stem height from the cut to the growth tip was measured to the nearest 0.1 cm (PH). The weight of the aboveground portion of the plant was recorded to the nearest 0.01g (PW) with an ACCULAB 221 electronic balance (Acculab Scales, Titusville, NJ). Stem diameter (SD) to the nearest 0.1 mm was measured at the base of the stem. Leaf length to the nearest 0.1 cm (LL) was measured from the junction of the petiole and blade to the tip. Leaf width to the nearest 0.1 cm (LW) was measured at the widest point of the leaf blade, and root weight to the nearest 0.01g (RW) was also measured. The ratio of leaf length/width (L/W) was calculated for each leaf. The measurements from the three sets of five seedlings were pooled and compared to their in-group controls via a student's t-test corrected for small sample size. Since with such a small sample the results could well be skewed by an aberrant value, any outlying values (> 2 S.D.) were discarded, and the results recalculated as additional experimental or control plants were added to the number. In no case was n less than 15. Anova revealed that the controls could not be pooled across data sets, but could be within each.

3. Results

3.1. Seedling emergence

When the static field was reduced to zero, sprouting was identical to normal controls. Since the lines are nearly identical, they are not included on the figures, as they would contribute nothing.

Tuning for ICR produced pronounced effects on sprouting in some cases. Figs. 1–3 illustrate the results. At the fundamental tunings (Fig. 1), potassium accelerated sprouting, while calcium was inhibitory. Magnesium produced no significant effect. When odd harmonics were employed (Fig. 2), a different picture appeared. Calcium 3N tuning produced significant acceleration of sprouting for plants emerging after 5 d. Potassium at 3N produced general acceleration of sprouting, and the effect at 3N was even more pronounced than at the fundamental. Magnesium 5N tuning produced a remarkable result. In contrast to the results at 1N, tuning at 5N was definitely stimulatory, but only for plants appearing before day 6. This is opposite to the acceleration by calcium tuning. When even harmonic tunings were employed (Fig. 3), there were no significant differences from controls.

3.2. Growth at fundamental ICR tunings

Results at the fundamental frequencies are shown in Tables 1–3 and Figs. 4–6. The tables present the paramet-

Ca⁺⁺, K⁺, and Mg⁺⁺ 1N Germination

60 Hz, 40 microT P-P, 24 Hr

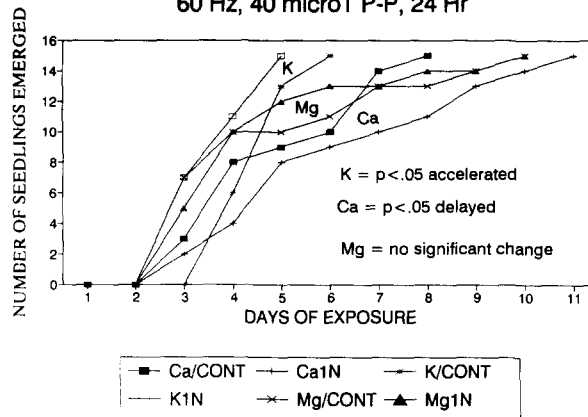


Fig. 1. Effect of ICR tuning at fundamentals for Ca²⁺, K⁺ and Mg²⁺ ions on radish seed germination. Ionic symbols between pairs of lines on the graph lie between experimental and control curves for that ion. Only Ca²⁺ and K⁺ tunings are effective.

Ca 3N, K 3N, Mg 5N GERMINATION

60 Hz, 40 microT P-P, 24 Hr

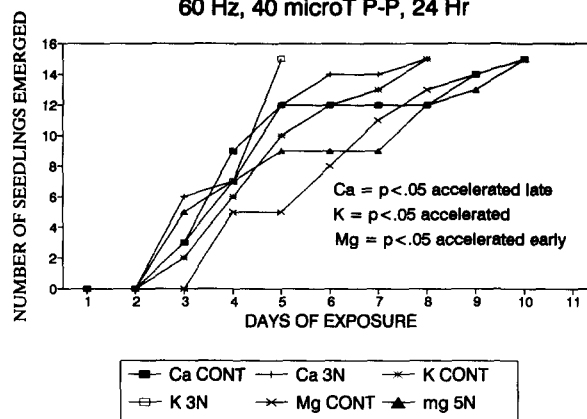


Fig. 2. Effect of ICR tuning at odd harmonics for Ca²⁺, K⁺ and Mg²⁺ ions on radish seed germination. All three ions are effective.

Ca⁺⁺ and K⁺ 2N Germination

60 Hz, 40 microT P-P, 24 Hr

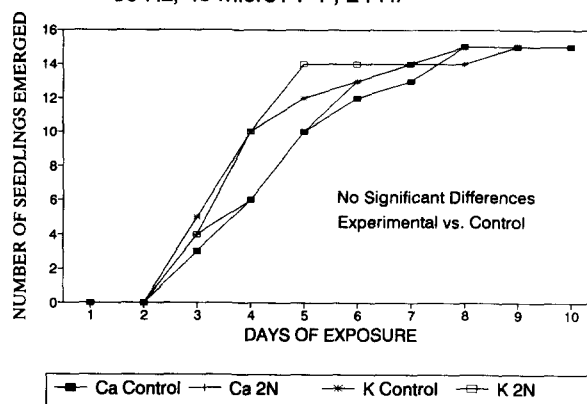


Fig. 3. Effect of ICR tuning at even harmonics for Ca²⁺ and K⁺ ions on radish seed germination. Neither tuning is effective.

Table 1
AC and Ca²⁺ parametric data

	Parameter (n) ^a						
	PH (15)	PW (15)	SD (15)	RW (15)	LL (25)	LW (25)	LW (25)
Control	5.9 ± 0.9	0.17 ± 0.02	1.1 ± 0.3	0.3 ± 0.01	1.4 ± 0.5	0.9 ± 0.2	1.5 ± 0.2
ac only	5.9 ± 1.0	0.17 ± 0.04	1.1 ± 0.1	0.3 ± 0.01	1.4 ± 0.5	0.9 ± 0.3	1.5 ± 0.2
<i>t</i>	0	0	0	0	0	0	0
<i>p</i>	NS	NS	NS	NS	NS	NS	NS
Control	5.1 ± 1.4	0.27 ± 0.1	1.3 ± 0.3	0.06 ± 0.02	1.3 ± 0.8	0.9 ± 0.5	1.5 ± 0.4
Ca 1N	6.2 ± 0.8	0.38 ± 0.08	1.7 ± 0.3	0.11 ± 0.03	1.7 ± 0.6	1.2 ± 0.4	1.5 ± 0.4
<i>t</i>	2.5525	3.2139	3.5277	5.1887	1.9596	1.4697	0
<i>p</i>	< 0.05	< 0.01	< 0.01	< 0.001	= 0.05	NS	NS
Control	2.1 ± 0.6	0.14	1.1 ± 0.1	0.03 ± 0.01	1.1 ± 0.4	0.8 ± 0.2	1.3 ± 0.2
Ca 2N	2.4 ± 0.6	0.15	1.1 ± 0.1	0.03 ± 0.01	1.0 ± 0.4	0.8 ± 0.3	1.3 ± 0.2
<i>t</i>	1.1979	0.0798	0	0	1.0736	0	0
<i>p</i>	NS	NS	NS	NS	NS	NS	NS
Control	3.2 ± 0.7	0.18 ± 0.05	1.1 ± 0.1	0.03 ± 0.01	0.9 ± 0.5	0.8 ± 0.3	1.4 ± 0.2
Ca 3N	3.5 ± 0.8	0.20 ± 0.04	1.2 ± 0.1	0.04 ± 0.01	1.1 ± 0.4	0.9 ± 0.3	1.3 ± 0.1
<i>t</i>	1.0560	1.05830	2.6457	2.6457	1.53018	1.1547	1.63595
<i>p</i>	NS	NS	< 0.05	< 0.05	NS	NS	= 0.05

^a See text for abbreviations.

ric data, while the figures show the percent change from control. The 1N and 3N calcium and potassium data have been published previously [7,8], and are included here for clarity of comparison.

For calcium ion tuning (Table 1, Fig. 4), plant height, weight, stem diameter, root weight, and leaf length were

all significantly increased. Leaf width was increased, but the change was not significant. Aspect ratio was unchanged.

For potassium ions (Table 2, Fig. 5), plant height was unchanged. Stem diameter, leaf length, and leaf width were significantly reduced. Root weight was significantly

Table 2
K⁺ parametric data

	Parameter (n) ^a						
	PH (15)	PW (15)	SD (15)	RW (15)	LL (25)	LW (25)	LW (25)
Control	6.6 ± 1.6	0.29 ± 0.11	1.3 ± 0.2	0.04 ± 0.01	1.7 ± 1.3	1.0 ± 0.3	1.5 ± 0.2
K1N	6.6 ± 0.8	0.27 ± 0.06	1.2 ± 0.2	0.07 ± 0.02	1.2 ± 0.6	0.8 ± 0.4	1.7 ± 0.3
<i>t</i>	0	0.5972	2.0836	5.0200	2.0564	2.5505	2.2437
<i>p</i>	NS	NS	< 0.05	< 0.0005	< 0.05	< 0.05	< 0.05
Control	2.0 ± 0.4	0.15 ± 0.05	1.0 ± 0.2	0.03 ± 0.01	1.1 ± 0.4	0.9 ± 0.3	1.3 ± 0.2
K2N	2.5 ± 0.5	0.14 ± 0.03	1.2 ± 0.1	0.03 ± 0.01	1.1 ± 0.4	0.8 ± 0.2	1.3 ± 0.2
<i>t</i>	2.8566	0.06349	3.3189	0	0	1.0253	0
<i>p</i>	< 0.01	NS	< 0.005	NS	NS	NS	NS
Control	6.3 ± 1.0	0.23 ± 0.09	1.4 ± 0.2	0.04 ± 0.02	1.6 ± 0.6	1.0 ± 0.4	1.5 ± 0.3
K3N	5.2 ± 1.1	0.20 ± 0.07	1.1 ± 0.1	0.07 ± 0.02	1.3 ± 0.6	0.8 ± 0.4	1.7 ± 0.3
<i>t</i>	2.7686	0.9845	4.2852	3.9686	1.6914	1.9996	1.0775
<i>p</i>	< 0.05	NS	< 0.001	< 0.001	NS	= 0.05	NS

Table 3
Mg²⁺ parametric data

	Parameter (n)						
	PH (15)	PW (15)	SD (15)	RW (15)	LL (25)	LW (25)	LW (25)
Control	6.2 ± 0.9	0.18 ± 0.03	1.0 ± 0.1	0.03 ± 0.02	1.4 ± 0.4	0.8 ± 0.3	1.7 ± 0.3
Mg 1N	5.5 ± 1.0	0.18 ± 0.04	1.4 ± 0.3	0.05 ± 0.01	1.5 ± 0.05	1.1 ± 0.3	1.4 ± 0.2
<i>t</i>	1.9468	0	4.7329	3.3466	0.7651	3.4641	4.0420
<i>p</i>	= 0.05	NS	< 0.001	< 0.01	NS	< 0.01	< 0.001
Control	2.5 ± 0.4	0.17 ± 0.03	1.1 ± 0.1	0.03 ± 0.1	1.1 ± 0.4	0.7 ± 0.3	1.5 ± 0.2
Mg 5N	2.3 ± 0.6	0.20 ± 0.03	1.2 ± 0.1	0.05 ± 0.01	1.2 ± 0.2	0.9 ± 0.2	1.2 ± 0.1
<i>t</i>	1.0377	2.6458	2.6458	5.2915	1.0954	2.7175	6.5727
<i>p</i>	NS	< 0.05	< 0.05	< 0.001	NS	< 0.05	< 0.001

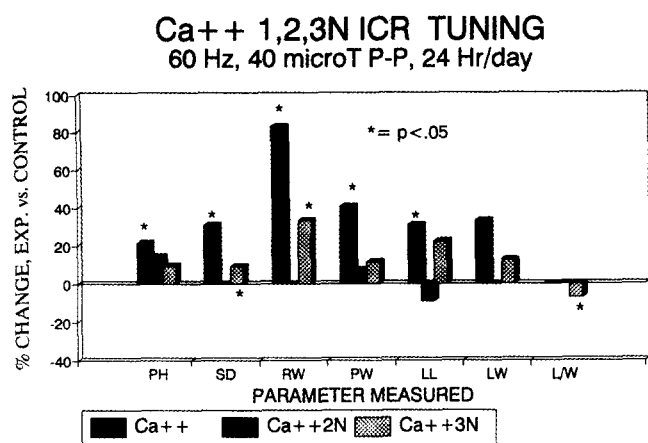


Fig. 4. Effect of ICR tuning at fundamentals for Ca^{2+} , K^+ and Mg^{2+} ions on radish seedling growth and differentiation.

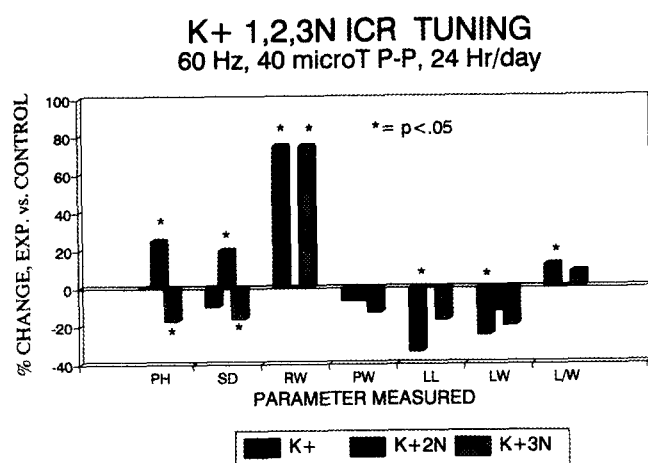


Fig. 5. Effect of ICR tuning for odd harmonics of Ca^{2+} , K^+ and Mg^{2+} ions on radish seedling growth and differentiation.

increased, as was aspect ratio (the leaves became significantly narrower). Plant weight was slightly reduced, but the change was not significant.

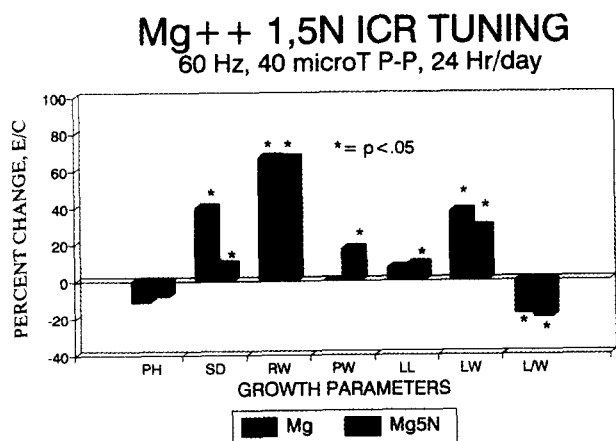


Fig. 6. Effect of ICR tuning for even harmonics of Ca^{2+} and K^+ ions on radish seedling growth and differentiation.

Magnesium tuning significantly increased stem diameter, root weight, and leaf width (Table 3, Fig. 6). Aspect ratio was significantly reduced (wider leaves). Plant height was reduced, but not significantly. Plant weight remained unchanged.

When the static field was cancelled (Table 1), the 60 Hz field elicited no effect whatsoever. All parameters were identical to their controls (though the standard deviations varied).

3.3. Growth at odd harmonic ICR tunings

Tuning for odd harmonics of the fundamental ICR frequencies for calcium, potassium and magnesium gave basically the same results as tuning for the fundamental. Tuning for the 3rd harmonic for calcium (Table 1, Fig. 4) produced increased plant height and weight, as with the fundamental, though the increases were not statistically significant. Root weight and stem diameter did increase significantly. Leaf length and width increased, but not significantly. In contrast to the fundamental tuning, the alteration in leaf shape was significant, with the leaves becoming somewhat broader and more rounded.

Tuning for the 3rd harmonic for potassium ions (Table 2, Fig. 5) produced results again similar to the tuning for the fundamental frequency. The basic trend was to inhibition, except for root weight. Height, plant weight, stem diameter, leaf length, and leaf width were all diminished, though the plant weight, leaf length, and leaf width changes were not statistically significant. The leaves were only slightly narrower than controls, in contrast to the fundamental tuning.

When the fields were adjusted to 5N for magnesium (Table 3, Fig. 6), the trends also were the same as for the fundamental tuning. Plant height was slightly decreased, while plant weight, stem diameter, and root weight increased markedly. Leaf length remained basically unchanged, but leaf width increased significantly, leading to a significant change in leaf shape — a much broader, rounded leaf.

3.4. Growth at even harmonic ICR tunings

Tuning for the even harmonics produced strikingly different results. As may be seen from Table 1, Fig. 4, tuning for the 2nd harmonic for calcium produced essentially no effect. There were no significant differences between the controls and the experimentals. When the fields were tuned for the 2nd harmonic for potassium (Table 2, Fig. 5) a striking result was obtained. The effects of this tuning were totally different from tuning for 1N or 3N. Plant height and stem diameter were significantly increased. The results were basically similar to a weak calcium effect, except for the failure of the field to produce an increase in root weight.

4. Discussion

The results for germination are puzzling. The stimulation of germination by potassium is in contrast to its generally inhibitory effect. Perhaps the result again reflects an effect on root growth, since the first visible event after seed swelling in germination is the appearance of the hypocotyl. The literature is not helpful.

The somewhat different germination effects of calcium and magnesium at the fundamental and odd harmonics are presently inexplicable. Again, the results may be due to some degeneracy in the harmonics. For example, the 3rd harmonic for calcium is within 2% of the 5th harmonic for zinc, and the 5th harmonic for magnesium is within 3% of the 15th harmonic for chloride. The change in results may have been due to a summation of the effects of ion pairs active at the harmonics but not at fundamental frequencies. Studies at the fundamental frequencies for zinc and chloride might prove illuminating.

Again, as for the even integer tuning effects on growth parameters, even integer tuning for calcium and potassium ions did not affect germination, and we conclude that the plants simply ignored the fields.

It is apparent from the data presented here that 40 μT peak–peak 60 Hz ac magnetic fields in the absence of a parallel static field have no effect on germination or seedling growth. The identical mean values for all parameters is surely a remarkable coincidence. Fortunately, the standard deviations vary somewhat between experimentals and controls. Other experiments with power frequency (50–60 Hz) fields have demonstrated a variety of effects, including alteration of gene expression (Goodman et al. [9]). The Goodman experiments were done at considerably lower field levels (5.7 μT , rms), and indicated a strong “window” effect of field strength, so our results may perhaps be attributed to the fact that the fields we used were simply too strong to see such an effect. In most other studies the static magnetic fields were not measured or controlled, so it is impossible to ascertain if ion resonance conditions were satisfied. However, some studies, e.g. those by Blackman et al. [10], are notable exceptions and do demonstrate apparent resonance effects.

The present studies also clearly demonstrate that a definite effect can be produced by tuning to the ICR fundamental frequencies for common metabolically important cations. Further, it is clear that the effects of tuning at the fundamental and 3rd harmonic are essentially similar for calcium and potassium, and for the fundamental and 5th harmonic for magnesium. Examination of the data also shows that there is statistically significant ($p < 0.05$) variation in many of the control values from experiment to experiment. This fact makes it clear that any experiments on plant systems should have concurrent controls as a component of the design. The variations may be attributable to a number of factors. The age of the seeds (vitality does decrease over time) comes immediately to

mind, as does the time of the year when the tests are performed. Ruzič et al. [11] have shown a clear seasonal effect on plant growth and field response in chestnut buds.

The data presented here also appear to refute any claims for a nonspecific effect. The effects of all three ions are characteristic, and the patterns of change are ion-specific, except for root weight, which increased in all odd integer categories. This is perhaps to be expected. A general growth-inducing effect by calcium and magnesium would be expected to produce an increase in root weight as part of that general effect. The increase in root weight as a result of potassium tuning is not surprising, given the role of potassium in plant root development generally, and in root crops such as radishes, particularly. The opposite changes in leaf shape as a result of tuning for magnesium or potassium are remarkable, and there is no clear reason for it. Perhaps one could argue that magnesium, being so important for leaf metabolism and production of chlorophyll would be expected to produce a change favoring larger leaves with greater relative area, and that the potassium effect reflects an alteration of the growth pattern to favor roots over leaves. Obviously, we have no data to indicate the exact nature of the effect, and some experiments on auxin/enzyme levels and activities are clearly in order.

The results with the 2N tunings indicate that at least one even integer harmonic is ineffective. If one looks at the calcium 2N data, it is clear that 2N is basically similar to ac alone; no significant changes occurred. For potassium, the story is slightly different. The 2N tuning produced significant alteration in plant height and stem diameter, but the direction was opposite to that seen for 1N and 3N. The explanation probably lies in the fact that the second harmonic for potassium (76.6 μT) and the fundamental for calcium (78.4 μT) are only 2.3% apart. The fact that there is a clear difference between the 2N potassium and calcium at the fundamental suggests that the resonance tuning peak for calcium is relatively sharp.

In sum, the results of these experiments clearly demonstrate that ICR at the fundamental and some odd harmonic tuning points can effect changes in radish seed sprouting and subsequent early plant growth. Insofar as these results stand by themselves, they support the ICR hypothesis, but do not support the Parametric Resonance hypothesis of Lednev [12], nor its expansion as the Ion Parametric Resonance hypothesis of Blanchard and Blackman [13], since 2N tunings are ineffective. A series of 1/2N tunings would help to clarify the validity of the ICR hypothesis. Such tunings should also be ineffective if ICR is operational.

It is impossible from these data to make a decision as to the precise site of action of the fields. We assume that it is in the membrane channel [2], but that is not necessarily the case. Our assumption is based on the fact that in an hydrated system, the ions would be surrounded by a considerable shell of water molecules, and resonance would

be impeded by hydrodynamic “drag”. For ICR to be effective, one must posit some place where the ions are either naked, or at least free to move with relative lack of hinderance. The channel seems like a plausible site. Given the power levels employed, it is implausible to suggest that the fields “drive” the ions. The assumption in [2] is that the envelope of ionic movement is adjusted to “fit” the channel. Alternatively, one could propose action at a binding site where the ion sheds water or attaches to some receptor. Alternative explanations reflecting such alterations in binding probability are also plausible, and have been advanced by others [12–14]. The interested reader is directed to Berg and Zhang [15] for a relatively comprehensive review of current theories.

In any case, the data do certainly argue strongly that some sort of resonance mechanism is present. We now must determine exactly what kind, then how and where it is operational.

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